(9) To: Water Resources — Plastics in Construction

United States Department of the Interior

BUREAU OF RECLAMATION

ENGINEERING AND RESEARCH CENTER

STATINTL

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IN REPLY REFER TO: 1400
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JUN 14 1974

Mr. Ray Durazo
Mr. J. P. McGarvey
Mr. Walter J. Ochs
Mr. Robert E. Phillco [redacted]

Gentlemen:

I just received a cable from Mr. Kolesnikov, U.S.S.R. Ministry of Reclamation Water Management, advising me that they concur in our program; that they will arrive in this country on July 5; and that the names and titles of the Soviet Working Group on Plastics in Construction are:

Sviklis - Director, Latvian Research Institute
Kharin - Deputy Director, Ukrainian Research Institute
Blinov - Laboratory Chief, Research Industrial Corporation Plastics
Korbut - Woman Interpreter

In addition, an interpreter from the State Department will travel with us as well as Mr. Peterson of the U.S.S.R. Embassy staff, who expects to accompany us except to California sites.

There has been a recent change in the itinerary that will have the immediate effect of changing some of the plane reservations you assumedly have already made. Changes are as follows:

July 9, Tuesday

(No change in schedule regarding visit to Florence, S. C.)

Leave Atlanta, Delta #1038 (Snacks) 10:31 a.m.
Arrive Chicago, Illinois 11:07 a.m.
Ground transportation and program by Arco Polymers, Inc.

July 10, Wednesday

Ground transportation and program by Arco Polymers, Inc.

CL's / KES / OSI / ORR / OSS / OBGI (Bss)

file Water Resources

Water Resources

July 11, Thursday

Ground transportation by Arco Polymers, Inc.

Leave Chicago, United Air Lines #143	10:05 a.m.
Arrive Seattle, Washington (Lunch in flight)	12:05 p.m.
Leave Seattle via ground transport. Transportation furnished by Hancor, Inc.	12:30 p.m.
Arrive Olympia, Washington	2:30 p.m.

July 12, Friday

Ground transportation and program including visit to Hancor Plant in Olympia by Hancor, Inc.

July 13, Saturday

Leave Olympia via ground transport. Transportation furnished by Hancor, Inc.	9:00 a.m.
Arrive Seattle, Washington	11:30 a.m.
Leave Seattle, Air West #324	12:05 p.m.
Arrive Spokane, Washington	12:48 p.m.
Lodging at Holiday Inn West	

The remainder of the itinerary is firm. I will furnish you an updated itinerary reflecting the above changes and lodging arrangements soon.

Thank you for your comments on the resume of the state of the art. Enclosed is a copy of the revised document. I have made arrangements to have it translated into Russian.

Sincerely yours,

/s/ Harold

H. G. Arthur
Director
Design and Construction

Enclosure

U.S. WORKING GROUP'S RESUMÉ

ON

PLASTICS IN (HYDROTECHNICAL) CONSTRUCTION

FOR

U.S.-U.S.S.R. JOINT COMMISSION

ON SCIENCE AND TECHNOLOGY COOPERATION

JUNE 1974

PLASTIC FILMS FOR CANAL LININGS

The Bureau of Reclamation has had a long and continuing interest in the development of new materials for use on irrigation projects. Within the past 20 years, the rapid development of synthetic polymers has made a host of new materials available; however, specific research and development aimed at irrigation and drainage requirements were somewhat slower. Through the cooperation of industry, Reclamation has conducted extensive laboratory and field research on many of these synthetic materials engineered specifically for these requirements.

Since the start of Reclamation investigations in 1949, at least 135 assorted plastic film or sheeting samples, such as polyvinyl-chloride (PVC), polyethylene (PE), and ethylene vinyl acetate copolymer (EVAC), from 0.03 mm (1 mil) to 0.064 mm (25 mils) thick, supplied by about 20 different manufacturers, have been examined and tested. These films have been found to be highly resistant to bacteriological deterioration, and the tensile strength and flexibility are virtually unaffected by exposure to soil burial for 10 years. Many plastic films deteriorate relatively rapidly when exposed to sun and weather. Plastic film, even in 0.04 mm (1-1/2-mil) thickness, is essentially a watertight material; however, a film less than 0.20 mm (6 to 8 mils) thick is rather easily damaged when placed over rough subgrade or covered with angular materials. The minimum thickness recommended by the Soil Conservation Service, Department of Agriculture is 0.20 mm (8 mils). Reclamation, whose canals and hydraulic works are generally larger than those of the Soil Conservation service, recommends a minimum thickness of 0.25 mm (10 mils).

INTRODUCTION

This resumé covers, briefly, the state of the art in the United States of Plastics in (Hydrotechnical) Construction. The primary contributor to this resumé has been the U.S. Bureau of Reclamation, the governmental agency with responsibility for developing water resources systems encompassing irrigation in the arid Western part of the United States. Other Federal agencies contributing to this resumé, and having extensive responsibilities in water resources, were the U.S. Department of Agriculture and the Corps of Engineers. Private industry manufactures plastic products and provides the basic research for their development. Industry's contributions were accordingly in these areas.

The resumé has been organized into the four areas of interest agreed upon; namely, (1) canal and reservoir linings, (2) polymers for soil stability and slopes, (3) plastic pipe for drainage and irrigation, and (4) polymer concrete. As an additional area of expected interest, a description of plastic joint sealers in concrete is included.

LABORATORY TEST RESULTS

Accelerated soil burial testing (acceleration estimated to be 5 to 10 times that of field conditions) showed polyethylene plastic lining to be highly resistant to bacteriological deterioration. Tensile strength and elongation properties were only slightly affected after 7 years' soil burial testing.

There was notable gain in tensile strength and loss in elongation properties of polyvinyl-chloride (PVC) plastic lining subjected to 7 years of accelerated soil burial. This change in strength and elongation is attributed to partial loss of plasticizer causing stiffening of the material.

It is indicated that the strength and elongation properties of ethylene vinyl acetate copolymer (EVAC) and chlorinated polyethylene plastics, like the polyethylene, are only slightly affected by soil burial.

The average original tensile strengths determined for chlorinated polyethylene, polyethylene, PVC, and EVAC are 1,800 (126), 2,100 (147), 2,600 (182), and 2,800 (196) psi (K/Cm^2), respectively. The average percent elongations were determined to be 300 for PVC, 500 for polyethylene, 550 for chlorinated polyethylene, and 700 for EVAC.

Hydrostatic puncture tests over coarse and fine rock showed that the plastic materials in the order of decreasing puncture resistance are PVC, EVAC, chlorinated polyethylene, and polyethylene. The 10-mil-thick materials tested over 3/4-inch (1.9 cm) to 1-1/2-inch (3.8 cm) size rock punctured at average water pressures of 30 psi (21K/Cm^2) for PVC, 26 psi (18K/Cm^2) for EVAC, 10 psi (7K/Cm^2) for chlorinated polyethylene and 9 psi (6K/Cm^2) for polyethylene. Elmendorf (modified Spencer attachment) impact puncture resistance determined for typical 10-mil-thick plastics showed PVC the best (2,400 grams), chlorinated polyethylene next (1,800 grams), polyethylene next (1,500 grams), and EVAC the lowest (1,400 grams).

Stiffness test results indicated that the typical 10-mil-thick plastics in the order of decreasing pliability are chlorinated polyethylene, PVC, EVAC, and polyethylene, having stiffness values of 1,000 (70), 2,000 (140), 6,000 (420), and 20,000 (1,400) psi, (K/Cm^2), respectively.

Based on Elmendorf tear tests, the plastic demonstrating the highest tear resistance was the PVC, followed by polyethylene, chlorinated polyethylene, and EVAC.

The polyethylene, chlorinated polyethylene, and EVAC plastics are highly resistant to cold temperature (0° F) impact fracture. All samples tested met the minimum test requirement of not more than 2

specimens out of 10 fracturing when impact tested at 0° F temperature. Out of 40 PVC samples tested, 9 failed to meet the cold-impact test requirement.

Polyethylene and PVC plastics are vulnerable to deterioration after 4 to 7 years of outdoor exposure. Polyethylene is slightly more resistant to sunlight and weathering conditions than the PVC plastics.

Solvent, heat, and electronic seam sealing are acceptable methods for factory fabricating PVC sheeting into large lining pieces. These sealing methods, if properly controlled, will provide seam strength from 85 to 100 percent of the plastic sheeting strength.

FIELD INVESTIGATIONS

Polyvinyl-chloride (PVC) and polyethylene plastic films have been installed on a limited scale on a number of Reclamation projects for evaluation purposes. Such installations have been made on the W. C. Austin Project, Oklahoma; the Gila Project, Arizona; the Huntley and Sun River Projects, Montana; the Boise Project, Idaho; the Yakima Project, Washington; the Tucumcari Project, New Mexico; and the Shoshone Project, Wyoming. The earliest polyethylene plastic lining installation was made in 1953 on the Huntley Project, with more recent installations made in 1961 on the W. C. Austin and

Tucumcari Projects. The polyvinyl-chloride plastic lining was first installed in 1957 on the Shoshone Project and the most recent installation was made in 1966 on the Sun River Project. One installation of ethylene vinyl acetate copolymer was made in 1968 on the Mirage Flats Irrigation District, Nebraska.

Periodic field evaluations have generally indicated that the plastic linings installed as buried membranes are performing very satisfactorily. In several installations where polyethylene and PVC plastic films were installed as exposed lining, the lining materials failed after about 3 years' service. This failure was largely due to the deteriorating effects of sunlight.

During October 1964, a detailed examination was made of 8-mil PVC plastic lining in service 7 years on the Shoshone Project. For this installation, the plastic membrane was covered with 4 inches (10 cm) of earth and a 5-inch (13 cm)-thick gravel blanket. After 7 years, much of the earth cover on the side slopes became infested with heavy growth of a tall grass and a scattered growth of cattail plants. The earth cover was removed near a vigorous cattail plant and it was observed that the root growth, although massive, lay along the top of the plastic membrane with no root penetration or other damage apparent. Also, an area of the plastic membrane was uncovered and a 3-foot (0.9 m)-square sample was obtained for laboratory testing.

It was observed that the 7-year-old plastic membrane was in excellent condition. Laboratory tests made of the sample showed that with exception of low temperature impact, the plastic membrane still met the physical properties requirements of Reclamation specifications for PVC plastic lining. Also, laboratory tests indicated that the puncture resistance of the plastic membrane was virtually unchanged.

In the spring of 1965, an examination was made of 4-year-old installations of 10-mil polyvinyl-chloride and polyethylene plastic lining on the Tucumcari Project. Areas about 4 feet (1.2 m) square were excavated by hand to expose the polyethylene and PVC linings to evaluate their condition and obtain 3-foot (0.9 m)-square samples for laboratory testing. Both lining materials were observed to be in good condition and providing a watertight membrane. It was noted that the PVC plastic could be treated quite roughly, by scraping action of shovels during the uncovering operation, without resulting in damage; whereas it was impossible to uncover the polyethylene plastic without some puncturing. It was indicated that the change in physical properties after 4 years' field aging has been very slight for both the PVC and polyethylene plastics. Both are still well within the limits of Reclamation specifications requirements. The pressure cell test results show that the puncture resistance of the 4-year-old PVC and polyethylene plastics is about the same as the original materials.

Also on the Tucumcari Project, an examination was made of a 3-year-old installation of buried 10-mil PVC plastic lining to evaluate weed penetration and the general condition of the membrane. The site selected was an area where heavy cattail infestation existed prior to lining and had reoccurred in the cover material since installation of the plastic lining. An area of the plastic lining 8 feet (2.4 m) wide by 30 feet (9.1 m) long was uncovered and carefully inspected. The plastic membrane was found to be in excellent condition. It was observed that the dense root system of the cattails growing in the cover material lay on top of the plastic film.

In all the areas examined, only one puncture was detected. There was evidence that this puncture resulted from a cattail rhizome growing from a plant in the earth cover getting under the plastic through a small hole (apparently torn during installation) and then puncturing through the membranes as it grew upward.

To determine the watertightness of buried plastic lining, ponding seepage tests were conducted on 3-year-old installations of 10-mil PVC and polyethylene plastic membrane on the W. C. Austin Project. After correcting for evaporation, the seepage losses were determined to be 0.05 and 0.13 cu ft/sq ft per day (15.24 and 39.62 $1/m^2$ per day) for the PVC and polyethylene linings, respectively. Another ponding test was conducted on 8-mil PVC buried plastic lining after 10 years service on the Shoshone Project.

PLASTIC LINING CONSTRUCTION

Construction of buried plastic lining requires that the canal or lateral cross section be overexcavated a minimum of 1 foot (.3 m) to provide for placement of protective cover material. The side slopes should be sufficiently flat to produce a stable condition for maintaining the cover material on the slopes under operating conditions. The proper side slopes will depend upon the type of cover material used; and under the best of conditions, the slope should not exceed 2 to 1. For 2 to 1 slopes, it is recommended that the protective cover consist of a free-draining irregularly shaped sandy to gravelly material.

After the rough excavation is completed, the subgrade for plastic lining should be prepared to a firm, relatively smooth surface. Sharp rocks, roots, and other objects that might puncture the membrane should be removed or padded by covering with 3 or 4 inches (8 or 10 cm) of sand or fine-textured soil. Dragging the subgrade with a heavy marine-type chain or tractor track has proven to be a rapid and effective method for smoothing canal subgrade. Where rolling is required because of needed compaction or smoothing rough subgrade, a roller-modified backhoe produces good results on the canal slopes. For the bottom, pneumatic rubber-tired rollers have been used with good success. Anchor trenches about 1 foot (30 cm) deep are needed along the canal berms or slopes for burying the edges of the plastic lining and may be excavated by a patrol grader or other suitable equipment.

PVC plastic lining is supplied in large, shop-fabricated pieces, in widths of 61 feet (19 m) and to any length practical for handling, to minimize the amount of field joining required. This lining is generally supplied accordion folded in both directions so that the liner can readily be unfolded from a truck traveling on the canal bottom or berm.

Polyethylene plastic lining is available in seamless widths to 40 feet (12 m) and normally in custom roll lengths of 100 feet (30 m). The liner is folded several times and then rolled on a cardboard core. When installing, the liner is unrolled into the bottom of the canal, then unfolded and placed into position.

Installation of plastic lining in a canal is normally begun at the downstream end. When tied into concrete structures, the ends of plastic lining are cemented to the concrete surface with asphalt mastic similar to roof flashing compound. Where not tied into structures, the ends of the plastic lining should be buried into 12-inch (30 cm) -deep transverse cutoff trenches. It is important that the plastic lining be placed in a slack condition. Sections of PVC lining can be joined simply by lapping the downstream end of one section 2 feet (60 cm) over the upstream end of the adjacent section without use of adhesive. PVC plastic has the characteristic of bonding to itself under pressure; therefore, the pressure of the

earth cover will result in a sufficiently bonded joint. Polyethylene does not have this characteristic and adjacent sections should be joined by use of special cement and pressure sensitive tape or by folding the ends together and burying in a trench. The edges of the plastic lining should be buried in the anchor trenches at the time of installation to prevent removal of the lining by unexpected gusts of wind.

It is best to avoid windy weather when installing plastic lining; however, if special precautions are taken, plastic lining can be successfully installed during fairly high winds. These precautions are as follows:

1. Place the lining, as nearly as possible, moving in the direction of the wind.

2. Sufficient laborers should be used to hold the lining tightly to the ground as it is unrolled or unfolded from the container.

3. As the lining is placed on the subgrade, it should be weighted down immediately with temporary weights such as sand bags. Discarded rubber tires can be conveniently used as temporary weights by rolling them off a moving truck following the lining placement crew.

4. As soon as possible, the trenches anchoring the edges of the plastic should be filled and some cover material placed.

The cover material should be a well-graded sand and gravel placed along the bottom and side slopes of the canal to protect the plastic lining from exterior damage. The Bureau of Reclamation specifies that the cover material should be graded within the following limits:

Screen size		Percent passing (by weight)
3 inches	(7.6 cm)	90-100
1-1/2 inches	(3.8 cm)	80-100
3/4 inch	(1.8 cm)	65-100
3/8 inch	(.95 cm)	45-95
No. 4		30-85
No. 8		20-70
No. 16		10-55
No. 30		5-35
No. 50		0-20
No. 100		0-10
No. 200		0-5

In addition to the above requirements, the material shall have a uniformity coefficient of not less than 4 derived from the formula $C_u = \frac{D_{60}}{D_{10}}$ where C_u is the uniformity coefficient, D_{60} and D_{10} are the grain sizes for which 60 percent and 10 percent respectively of the material are smaller.

Protective cover placement should begin as soon as the plastic lining is judged to be properly positioned, jointed, and repaired if necessary. The cover material can be placed with draglines, conveyors, trucks, or by other means, preferably starting at the toe and working upslope. During the initial stages, careful inspection should be made to insure that the cover placement operations are not causing damage to the

plastic membrane. It is not necessary to compact the cover material by rolling; however, dragging is usually required to attain the required finished shape and uniform thickness. The protective cover must remain stable on the side slope of the canal, resisting sloughing, erosion, and wave action during the operation of the system.

Plastic membrane lining is considered a low cost seepage control measure for canals. On a volume basis, 10-mil-thick polyethylene lining can be purchased for about $0.18 per square yard and shop-fabricated large pieces of PVC lining for about $0.35 per square yard based on 1972 prices. Although the polyethylene material cost is about half that of PVC plastic, the placement cost of polyethylene is greater because smaller sections are used, necessitating more labor in making field joints. Also, because of its greater puncture resistance, PVC lining can tolerate somewhat rougher subgrade conditions and cover operations. This in some cases could enter into the overall cost.

The contract cost in 1972 of a completed PVC plastic lining installation, including overexcavation, subgrade preparation, furnishing and placing 10-mil PVC liner, and placing protective cover, may range between $1.50 and $2.00 per square yard.

Since plastic films are unaffected by most effluents from industrial plants, holding ponds and evaporation ponds lined with plastic membrane have become widely used. The Bureau of Reclamation used a buried polyvinyl chloride membrane to line a 6-acre (2.4 hectare) brine holding pond at their geothermal investigation site in the Imperial Valley, California.

The Port Authority of New York and New Jersey has recently used (PVC) polyvinyl chloride to line two large lakes that were filled with bay water to preload a tidal marsh deposit.

In Moab, Utah, the Texas Gulf Sulphur Company used PVC to line 23 evaporation ponds covering more than 400 acres (160 hectares).

POLYMERS FOR SOIL STABILITY AND SLOPES

In recent years a number of polymer materials have been formulated in liquid-applied systems for various construction uses including soil stabilization. Many of the products for soil stabilization are emulsions requiring only dilution with water for spray-on application. These emulsions are generally of the following types: polyvinyl acetate latexes, acrylic copolymers, alkyd resins, and synthetic rubbers. Much of the equipment that is available for application of liquid fertilizers, insecticides, and for spreading asphalt emulsions can be used to apply the water-based emulsions. However, the application system selected for the job must not entrain air.

A polyvinyl acetate latex emulsion was used at the Jordan Aqueduct to stabilize about 3,500 square yards (2,926 square meters) of coarse sand backfill material over the 78-inch (198 cm) diameter concrete pipe which was placed on a steep hillside near the intake structure. The emulsion was diluted with water on a 1:9 ratio, and the mixture was applied at 3 gallons per square yard (13.6 l/m^2). The stabilized depth was about 6 inches (15.2 cm). This work was accomplished in June 1972, and the treatment will provide erosion protection until vegetation can be established for permanent erosion control.

In the construction of the Fort Thompson-Grand Island 345-kv transmission line, forty-seven tower sites in dune sand areas required a chemical soil stabilization treatment. An adequate gravel source was not available for erosion protection and this necessitated the chemical treatment. The purpose of the treatment was to control wind erosion, and to increase the bearing strength of the sandy soil around the tower footings to prevent damage by cattle. A special, hard-base liquid asphalt prime material was selected to stabilize the dune sand, and the contractor used the following treatment procedure:

1. Level and shape the site area to drain.
2. Scarify and loosen the sand with a harrow.
3. Apply a one-coat coverage of liquid asphalt at the rate of 1 gallon/square yard (4.6 $1/m^2$).
4. Rescarify the area with a harrow.
5. Apply a second coat of asphalt at the rate of 1 gallon/square yard (4.6 $1/m^2$).

The above procedure provided good results with the penetration of the asphalt varying from 2 to 3 inches (5.1 to 7.6 cms). This work involved the treatment of approximately 18,500 square yards (15,460 m^2) and it was accomplished in June-July 1970. The treated sites were inspected in October 1973, and the asphalt protection in nonpasture areas appeared to be holding up quite

well. Only two of the forty-seven sites appear to support appreciable vegetation. In areas where there is heavy cattle traffic some damage has occurred to the protection around the tower footings which has resulted in minor erosion.

A soil stabilizing material, either the previously mentioned polyvinyl acetate emulsion or an acrylic copolymer emulsion, has been specified for use at Auburn Dam, California, for temporary erosion protection. The material will be sprayed on road slopes along temporary construction roads, the stockpile in the railhead area, and other disturbed areas as required. It will be applied at a rate of 1 gallon per square yard (4.6 $1/m^2$) of area at a dilution rate of one part emulsion to nine parts of water. Approximately 250,000 square yards (210,000 m^2) will be treated. The acrylic copolymer emulsion has been used by the Corps of Engineers, St. Louis District, in hydroseeding work on dikes and levees in the Mississippi Valley area.

Studies are also being conducted to determine the effectiveness of spray-on polymer materials for dust abatement; soil stabilization of prepared earthwork during delays in construction; erosion protection of canal and spoil banks; stabilization of gravelly materials for riprap and beach belt applications; and as mulching materials for use in revegetation work.

In addition to the liquid systems, polymer membrane materials are available for soil stabilization work. For example, a polyvinyl chloride film and a rubberized asphalt/polyethylene sheeting are being specified for use at Fort Thompson Substation to waterproof the Pierre shale foundation. The clay-shale expands upon wetting and this has caused severe nonuniform movement in the structures and electrical equipment. The sheeting is a self-adhering waterproof membrane material consisting of a polyethylene plastic film, 4 mils (0.1 mm) thick, coated on one side with rubberized asphalt, 60 mils (1.5 mm) thick. This material will be used to waterproof 14,000 square yards (11,700 m^2) around the structures in the switchyard. The polyvinyl chloride film, 10 mils (0.25 mm) thick, will be used in the open areas, involving approximately 60,000 square yards (50,000 m^2). Both membranes will be covered with a 6 inch (15.2 cm) layer of sand/gravel for protection against damage from traffic and weathering.

CORRUGATED PLASTIC TUBING FOR DRAINAGE

Corrugated plastic tubing for drainage in the United States has expanded from about 5,000,000 feet (1,500,000 meters) in 1968 to an estimated 30 to 50 million feet (9 to 15 million meters) in 1973. Plastic tubing has many advantages over concrete and clay pipe, primarily economic. It can be installed up to four times faster, is easier to handle, installation is better since there are no joints to pull apart, the water intake is more efficient since the perforations are continuous along the pipe and it can be priced about the same or a little less than concrete and clay pipe.

The early plastic pipe was manufactured to meet specifications set forth in the "Soil Conservation Service Engineering Practice Standards for Tile Drain - Code 606," dated November 9, 1967. This standard covered all types of drain tile but had no specific requirement or tests included to cover the new plastic tubing. With the rapid expanding use of plastic drain tubing, two Federal agencies, the Soil Conservation Service, Department of Agriculture, and the Bureau of Reclamation, Department of the Interior, working with the American Society of Testing and Materials, tubing manufacturers, the American Society of Agricultural Engineers, and a number of universities, developed specifications and testing techniques specifically for corrugated plastic drain tubing. These specifications are now being used by all Federal agencies and consumers throughout the United States and except for minor variations have the same requirements.

The tubing manufacturers have experienced some difficulties in manufacturing tubing that meets the specifications requirements, mainly in cutting slots or perforations that do not have part of the opening filled with uncut material. The poorly cut slots resulted in one Federal agency, the Bureau of Reclamation, stopping all plastic tubing installation on Bureau projects. The tubing manufacturers recognized this as an immediate and critical problem requiring resolution and one manufacturer at great expense and with a good deal of engineering ingenuity developed multiple drill heads that drill cleanly cut holes. Now, this drilled tubing meets all requirements and is acceptable to the Bureau of Reclamation and individual users of plastic drain tubing.

Special trenchers have been developed to install plastic drain tubing from 3 inches (7.62 cm) diameter to 8 inches (20.32 cm) diameter. These trenchers are fast excavators and some can dig through all but the hardest caliche or rock. They can either shape the bottom of the trench and blind the tubing with more permeable top soil or, where required, install a designed gravel envelope around the tubing. Use of these machines has increased the installation rate from about 6 feet (1.8 meters) per minute at depths of 7 to 8 feet (2.1 to 2.4 meters) up to 15 to 20 feet (4.5 to 6 meters) per minute at about the same depths. Grade is controlled on many of these trenching machines by the use of a laser beam system.

At the present time, most of the tubing is manufactured from high density polyethylene virgin plastic in sizes from 4 to 8 inches (10.1 to 20.3 cm). Rapid progress is being made in the manufacturing of 10- and 12-inch (25.4-and 29.5-cm) diameter tubing for collector drain systems. In the humid areas of eastern and mid-western United States, most of the tubing used is 4-inch (10.1-cm) diameter. In the arid west where drains are installed to control the water table in irrigated lands, only about 30 percent is 4-inch (10.1-cm) diameter, with 60 percent being 6-inch (15.2-cm) diameter and 10 percent 8-inch (20.3-cm) diameter. When requirement and standards to cover 10- and 12-inch (25.4- and 29.5-cm) tubing have been developed, these sizes will replace most concrete and clay pipe now being used for collector drains.

Greater amounts of plastic drain tubing are now being used for building foundation drainage. In 1968 most foundation drainage was accomplished with clay tile drains. In 1973, about 10,000,000 feet (3,000,000 meters) of plastic tubing were used by building contractors. With the expanded building boom, even greater amounts will be used in the future.

PLASTIC PIPE FOR IRRIGATION

The need for pressure pipe for irrigation has increased significantly in the past few years; therefore, plastic pipes have been investigated as additional source. Just recently the Bureau of Reclamation has included reinforced plastic mortar in their specifications as an alternative for reinforced concrete pressure pipe, noncylinder prestressed concrete pipe, pretensioned concrete cylinder pipe, asbestos cement pressure pipe, or steel pipe. Approximately 15 miles (24 kilometers) of reinforced plastic mortar pipe has been installed on Reclamation projects.

Reinforced plastic mortar pipe (RPM) is a composite of polyester resin, silica sand, and glass filament reinforcing. The RPM pipe is built up in layers on a rotating mandrel with alternate layers of resin, sand silicates, and glass filament. The pipe is manufactured in nominal 10- and 20-foot (3 and 6 meter) lengths with bell and spigot, rubber-gasketed joints. The available size range is 8 inches (20.3 cm) inside diameter (ID) to 54 inches (137 cm) (ID) and in head classes (internal pressure) from 50 to 450 feet (15 to 135 meters).

The Bureau of Reclamation included RPM pipe in their specifications after a 3-year cooperative study between Reclamation and industry. During this period concentrated efforts were made to evaluate the RPM pipe, when under the influence of all foreseeable service conditions, such as internal and external pressures, exposure to water, mild acids

and bases, and to solutions of constituents of soil to determine whether pipe would meet the Reclamation requirement of giving long-term service.

During these tests it was found that the physical properties of this pipe change adversely after exposure to aqueous environments; however, it was determined that the reduction of the pipe's physical properties were not so great as to preclude the use of RPM pipe in Reclamation specifications. RPM pipe, like other flexible pipe, has to be properly installed to prevent excessive deflections. The Bureau of Reclamation allows deflections to 5 percent of the pipe diameter. To insure that the allowable deflection is not exceeded, the soil around the pipe should be compacted to 0.7D (outside diameter) of the pipe.

Studies have been underway for some time into the possible use of other types of plastic pipe. Glass filament reinforced epoxy resin pipe, for instance, has remarkably high internal strength and chemical resistance; conditions where these properties would be most advantageous rarely occur in Reclamation projects so no great effort has been expended by Reclamation on this type of pipe. It is anticipated, however, that in the near future glass filament reinforced epoxy resin pipe may be needed in geothermal, desalination, or salt water facilities. At the present time private industry has the capabilities to manufacture this type of pipe in diameters ranging from 1-1/2 to 144 inches (3.8 to 365 cm).

In the area of thermoplastic pipes the main interest is in those manufactured from polyvinyl chloride resins. Reclamation has field tests underway on rigid PVC pipe and on a flexible nylon fiber reinforced PVC pipe. Indications to date are that rigid PVC pipe should serve as satisfactorily as other types of pipe in most circumstances and may well prove to be superior where unusually severe corrosive conditions exist. The flexible reinforced PVC pipe also is promising but will require more study.

The plastic industry has been quite active in this country supplying thermoplastic pipe for agriculture and turf and home gardening purposes. The following table shows the type, size range and amount sold in the United States during 1973.

	Type	Diameter Range		Amount	
		inches	centimeters	pounds	kilograms
Agriculture	PVC	1-1/2 - 15	3.8 - 38.1	140,000,000	63,000,000
Agriculture	PE	1/2 - 2	1.3 - 5.1	20,000,000	9,000,000
Turf & Garden	PVC	3/4 - 6	1.9 - 15.2	80,000,000	36,000,000
Turf & Garden	PE	1/2 - 2	1.3 - 5.1	60,000,000	27,000,000

CONCRETE-POLYMER MATERIALS

Three materials are being investigated:

1. Polymer-impregnated concrete (PIC) - Precast portland cement concrete impregnated by a monomer system which is subsequently polymerized in situ.

2. Polymer-cement concrete (PCC) - Monomer is added during mixing of portland cement, water, and aggregate, followed by polymerization.

3. Polymer-concrete (PC) - A composite formed by polymerizing a monomer and aggregate mixture.

PIC and PC have shown excellent potential for use as construction materials; studies on PCC so far have not been as successful.

Compared to conventional concrete, PIC and PC show impressive improvements in strength and durability. Tests so far have shown PC and PIC have about the same strength.

	Conventional concrete	Polymer impregnated concrete	Improvement factor
Compressive strength	4,000 to 5,000 psi	20,000 psi	4X
Tensile strength	400 psi	1,600 psi	4X
Modulus of elasticity	3.5×10^6 psi	6×10^6 psi	2X
Freeze-thaw durability	600 - 700 cycles	> 10,000 cycles	> 14X
Sulfate resistance	400 - 600 cycles	> 1,800 cycles	> 3X
Water absorption	6.5 percent	< 1/2 percent	> 6X

The Bureau of Reclamation's program includes development of process technology for fabrication of concrete-polymer materials and a comprehensive testing program to obtain data for design and construction of structures. Potential applications investigated have included desalting plants, draintile, culvert and sewer pipe, beams and wall panels, bridge decks, underwater structures, and tunnel liners and supports.

PLASTIC JOINT SEALERS IN CONCRETE

A. Joint Sealers in Concrete Lined Canals

Conservation of increasingly valuable water often dictates lining canals with portland cement concrete. Soon after concrete placement, shrinkage of the lining begins and cracks develop. At the present time, preventing such cracking is impractical; however, cracking can be reduced and controlled by providing both transverse and longitudinal contraction joints at proper intervals along the canal. A

weakened plane is formed at these intervals by inserting a PVC plastic-joint-forming waterstop into the fresh concrete. The crack develops at the weakened plane but the plastic waterstop prevents leakage from the canal.

Both transverse and longitudinal joints are recommended by the Bureau of Reclamation in canals having a lined perimeter of 30 feet (9.14 m) or more. Smaller canals may require joints in both directions if the subbase material warrants. Transverse joints are usually spaced 10 to 15 feet (3.05 to 4.57 m) apart for 2-1/2 to 4-inch (6.4 to 10.2 cm) -thick linings, depending somewhat on the properties of the subbase material. Generally, longitudinal joints should be placed on the side slope of the canal within 1 foot (.3 m) of the intersection with the invert. Additional longitudinal joints would be used if the invert of slope dimensions exceed 12 to 15 feet (3.66 to 4.57 m).

Several million feet of the PVC joint-forming waterstop have been installed in Bureau of Reclamation canals in recent years. Valid data on the quality of sealing is scarce; however, a ponding test of the 6- to 10-foot (1.8 to 3.05 m) -deep Pleasant Valley Canal, sealed in both longitudinal and transverse directions with PVC plastic waterstop, disclosed leakage of only 0.008 cu ft/sq ft per day (2.44 l/m^2 per day).

B. PVC Waterstop in Hydraulic Structures

The Corps of Engineers requires flexible waterstops in all concrete hydrotechnical structures on yielding foundations or on pile foundations and permits flexible waterstops in structures less than 100 feet (31 m) high on rigid foundations. They may be made of natural rubber, synthetic rubber, or polyvinyl chloride, but since 1960 almost all have been PVC. In dams and navigation locks they are placed in contraction joints spaced at intervals of 40 to 60 feet (12 to 18 meters). In cross section they are "dumbbell" shaped or have an irregular shape with numerous ribs or corrugations.

The principal difficulty in installing PVC waterstops is the problem of making field splices. The PVC must be heated by a thermostatically-controlled electric source which supplies sufficient heat to melt but not char the plastic. After splicing, a remolding iron must be used to reestablish the original shape. A split waterstop is convenient to use since it does not require dividing the form into two portions, but the difficulty of reuniting the two halves of the waterstop is so great that split waterstops are not normally permitted on important projects.

The Corps has conducted a large amount of research to determine the durability of PVC under unfavorable climatic conditions. It has demonstrated greater durability than most types of rubber. Performance of PVC waterstops in cold weather has been expecially good. When

temperature drops from 73° F (23° C) to 0° F (-18° C), tensile strength increases 50 to 100 percent although the ultimate elongation decreased by 50 percent. However, when specimens were stressed to 90 percent of ultimate elongation, reducing the temperature from 73° F (23° C) to -15° F (-26° C) did not produce failure.